MORPHOLOGY OF GALAXY CLUSTERS IN LARGE OPTICAL GALAXY SURVEYS

Florent Rostagni
Laboratoire Lagrange, OCA, CNRS, UNS
Equipe Galaxies & Cosmologie

OUTLINE

- Introduction
- Cluster sample
- Morphology and classification
- Perspectives
- Conclusion

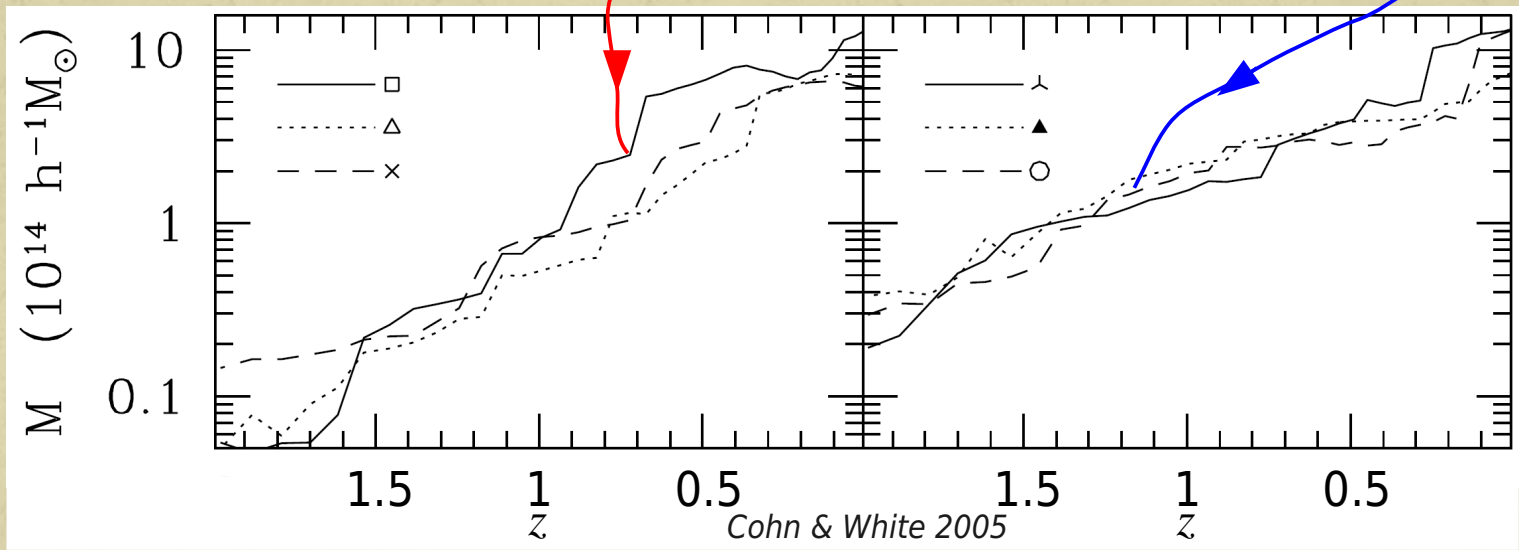
GALAXY CLUSTERS

Galaxy clusters = largest bound structures

Current model : hierarchical structure formation

How do clusters evolve?

Continous accretion of galaxies
Merging with groups or clusters



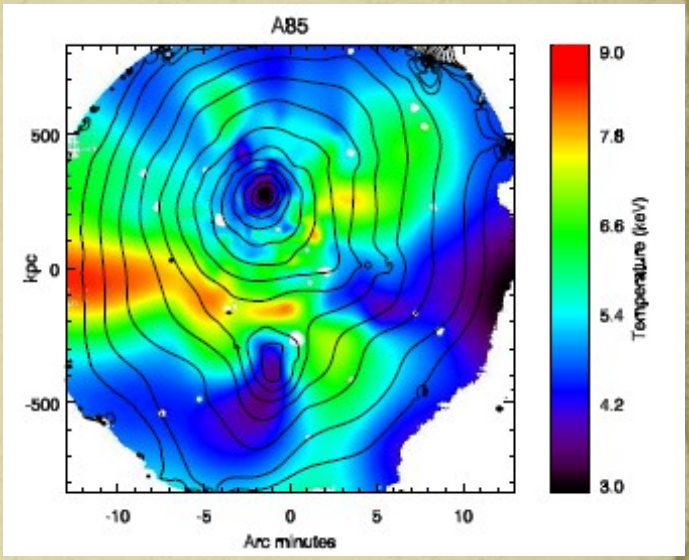
Cohn & White 2005

GALAXY CLUSTERS

Impact of merging on clusters :

Gas : collisional

→ Substructures
Signature on Tx



XMM - Courtesy H.Bourdin

Galaxies : collisionless

→ Substructures
Distorsion of the velocity distribution

GALAXY CLUSTERS

Mass ≠ no direct observable ⇨ Need to use proxies

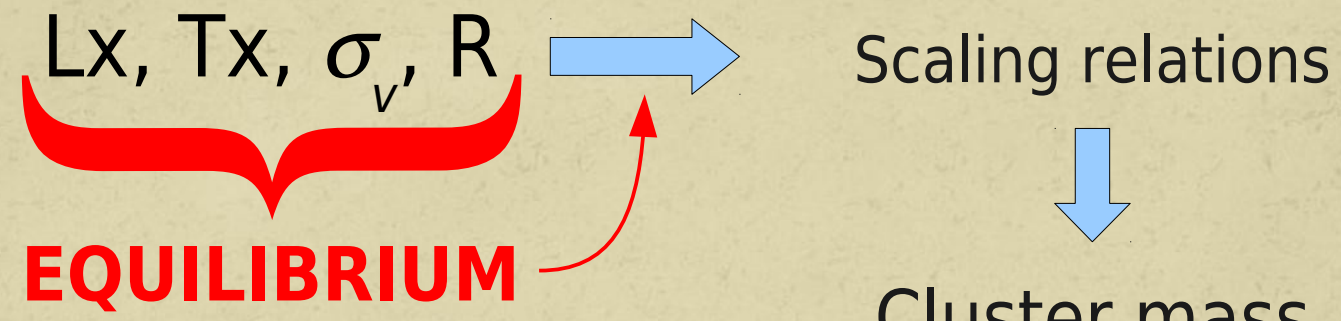
Lx, Tx, σ_v, R ⇨ Scaling relations

⇩

Cluster mass

GALAXY CLUSTERS

Mass ≠ no direct observable ⇨ Need to use proxies



GALAXY CLUSTERS

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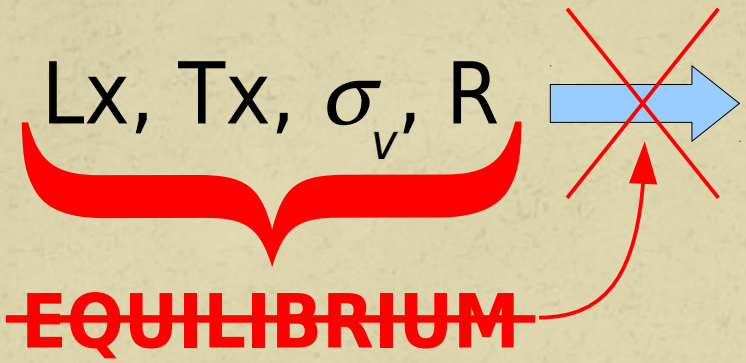


Scaling relations

⇩

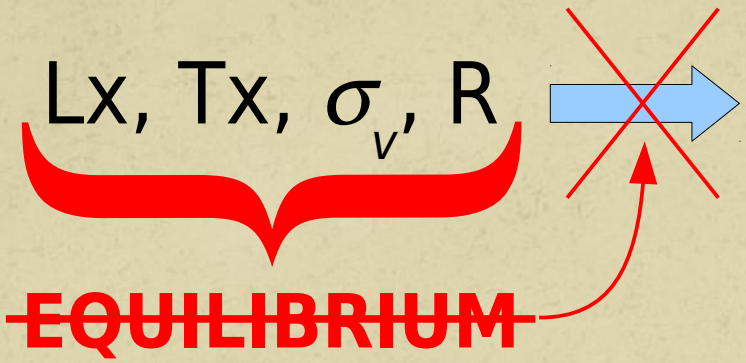
Cluster mass

Promising X-ray proxies Yx (Vikhlinin 2002)

⇨ IMPACT ON CLUSTER MASS FUNCTION

GALAXY CLUSTERS

Mass ≠ no direct observable ⇨ Need to use proxies



Scaling relations

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Cluster mass

Promising X-ray proxies Yx (Vikhlinin 2002)

⇨ IMPACT ON CLUSTER MASS FUNCTION

Clusters as cosmological probe: need to determine cluster dynamical state

⇨ Classification ⇨ How to identify complex clusters ?

GALAXY CLUSTERS

Identification of complex clusters :

Cluster dynamical state : optical **&** X-rays (Lx-Tx)

Large optical surveys (SDSS, CFHT-LS, DES ....)
Large X-rays surveys (ROSAT All Sky, XMM-LSS, XXL ....)

GALAXY CLUSTERS

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Morphology :

Different shapes
Different components
} Indicators

GALAXY CLUSTERS

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Morphology :

Different shapes
Different components } Indicators

Classification → Identify and characterize complex systems

CLUSTER CLASSIFICATIONS

OPTICAL	X-rays
Galaxy content Velocity distribution Density map	Centroid shift Power ratio
- projection effect	+ less projection effect

New morphological classification : 1+2D

Use redshifts to separate structures along the line of sight
Study velocity/redshift distribution and galaxy projected distribution

CLUSTER SAMPLE

SDSS : 2500 deg² ; 10^6 galaxies

- photometry complete up to r = 22
- spectroscopy complete up to r = 17.77

Miller et al 2004 : 749 clusters with the C4 algorithm

Extraction of galaxies within an aperture radius of 5Mpc at the C4 cluster redshift, up to r = 17.77

749 C4 fields with galaxy information :

(α, δ), u, g, r, i, z and z_{spec}

CLUSTER SAMPLE

Selection :

- Ngal > 50
- Spectroscopic redshift completness > 50 %
- Exclude detections closer than 5Mpc to SDSS DR7 edges
- Merge detections closer than 2Mpc

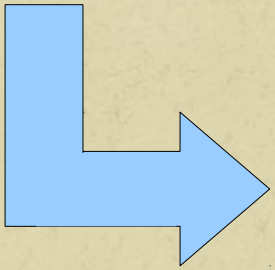
➡ 463 clusters with new coordinates (α, δ, z)

$z \in [0.03;0.17]$, $z_{med}=0.088$

150 km/s < σ_v < 2500 km/s

MORPHOLOGY

Deviations to a regular (relaxed) cluster :



Gaussian velocity distribution
Spherical

1+2D morphology : wavelet analysis

- along the line of sight
- in projection on the sky plane

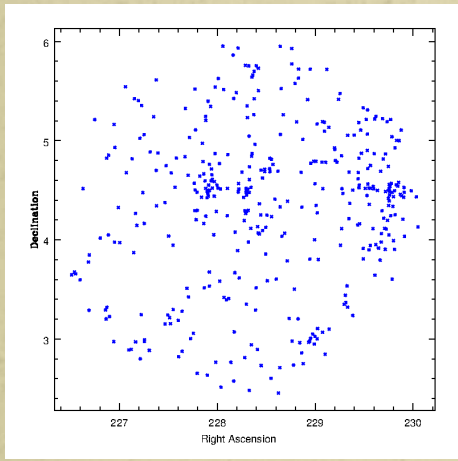
- use of redshift to disentangle piled up structures along the line of sight

WAVELET APPROACH

Evaluation of distribution functions

Projected density maps :

- Point catalog



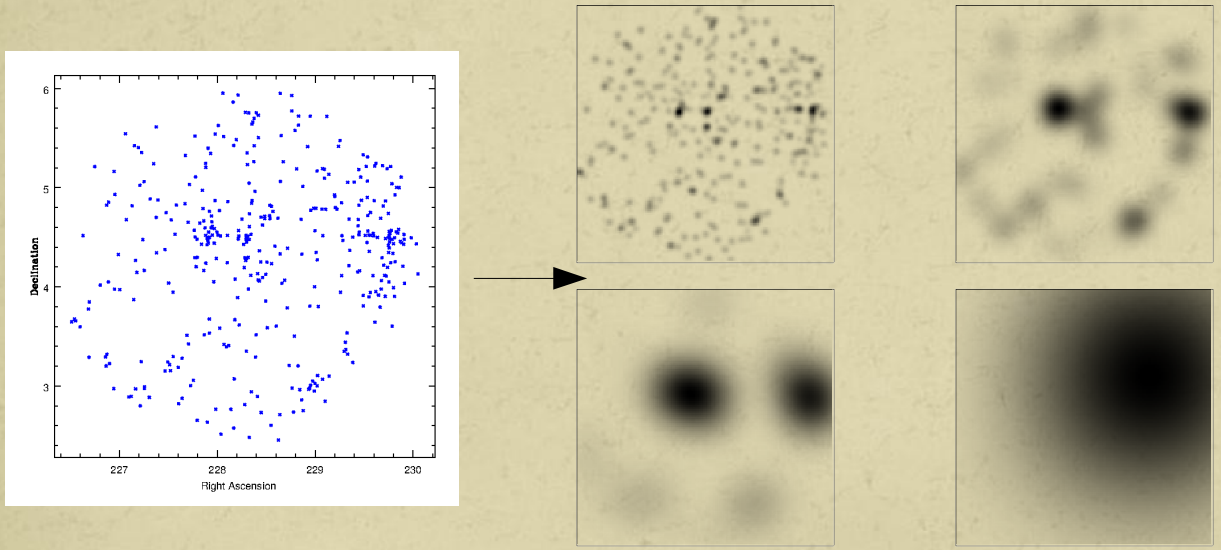
Rué & Bijaoui 1997, Ferrari et al 2005

WAVELET APPROACH

Evaluation of distribution functions

Projected density maps :

- Point catalog
- Perform the wavelet decomposition (pixel size)



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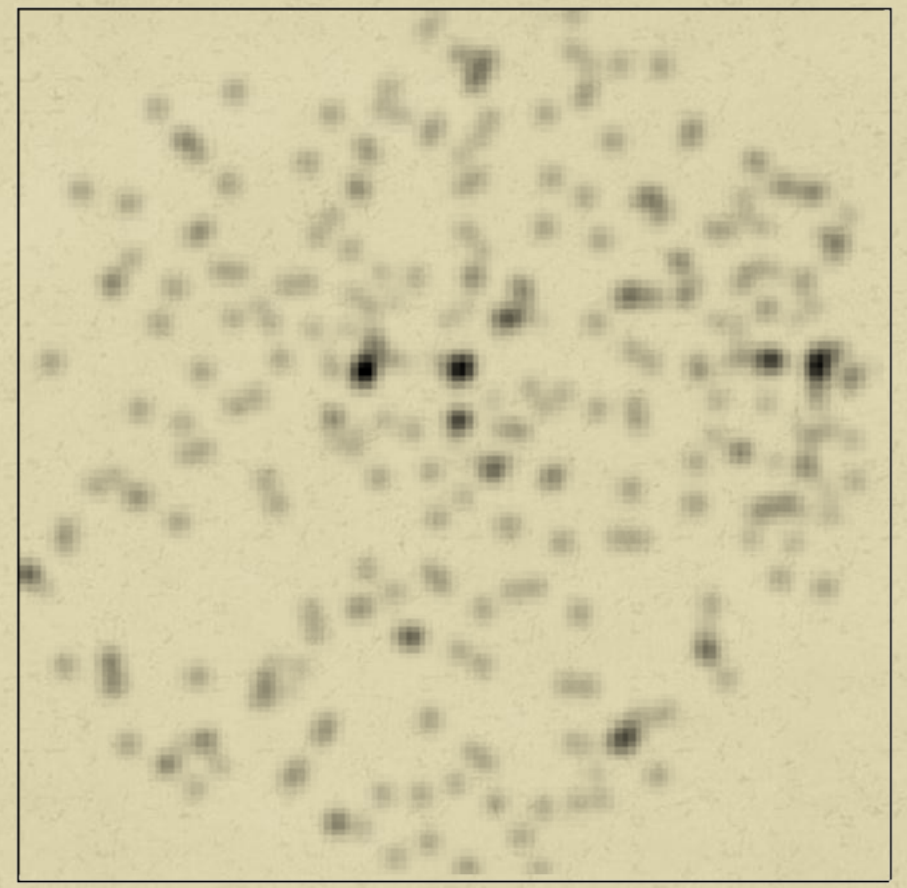
WAVELET APPROACH

Scale 2



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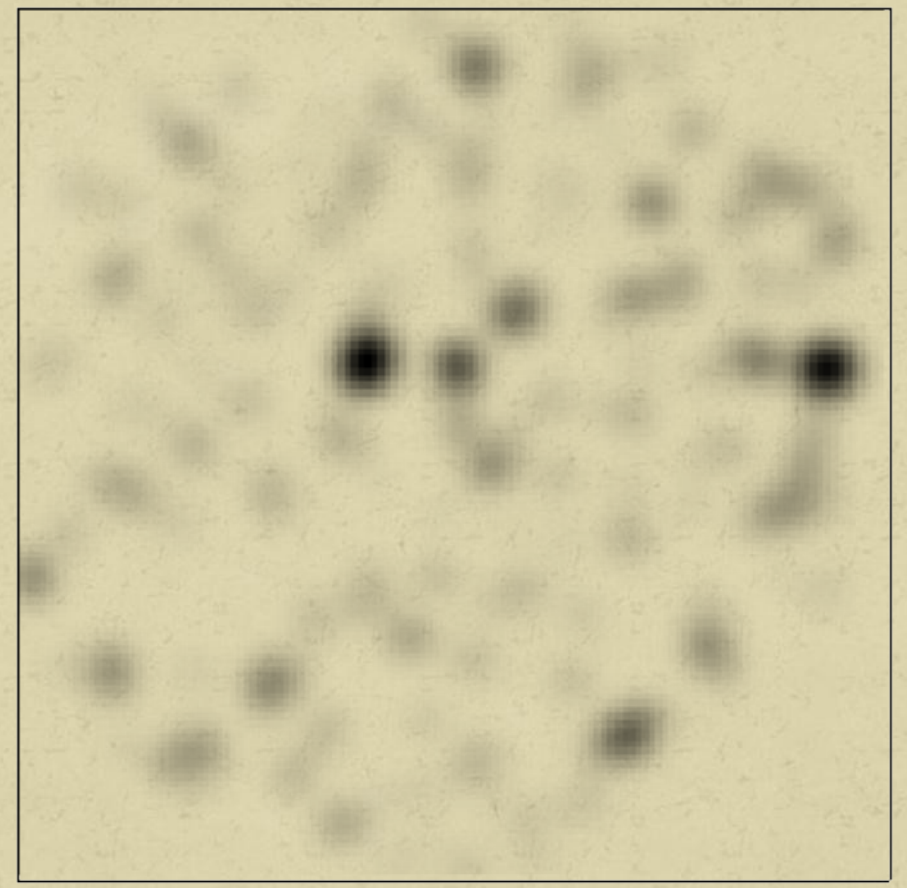
WAVELET APPROACH

Scale 3



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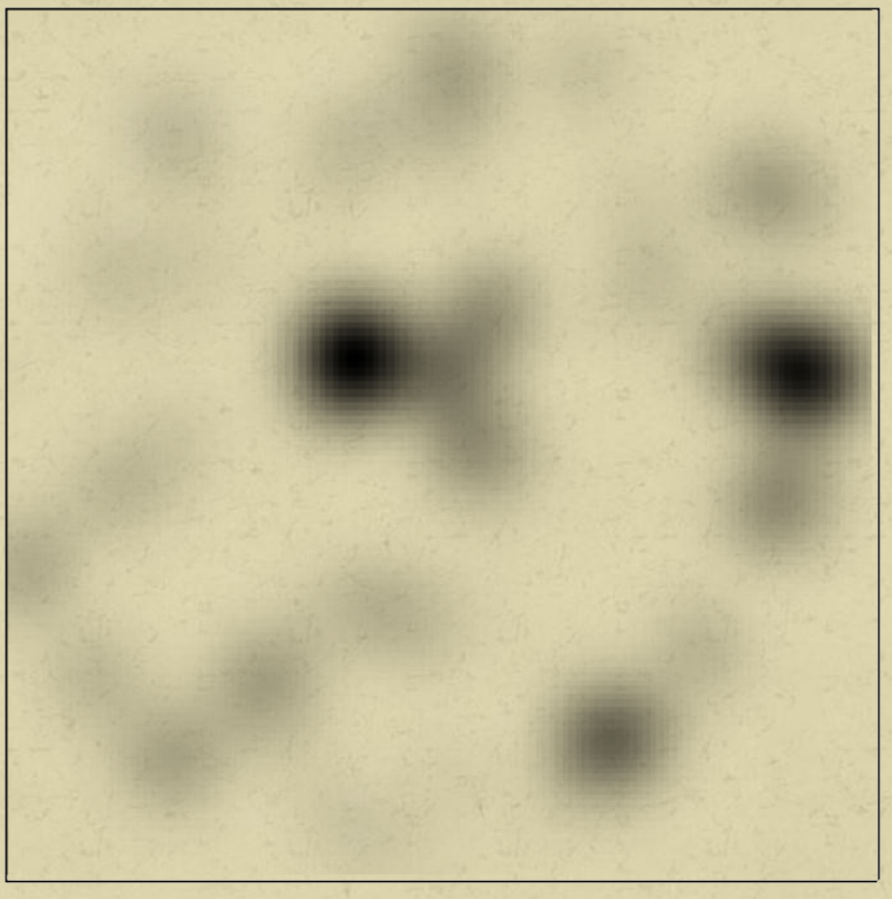
WAVELET APPROACH

Scale 4



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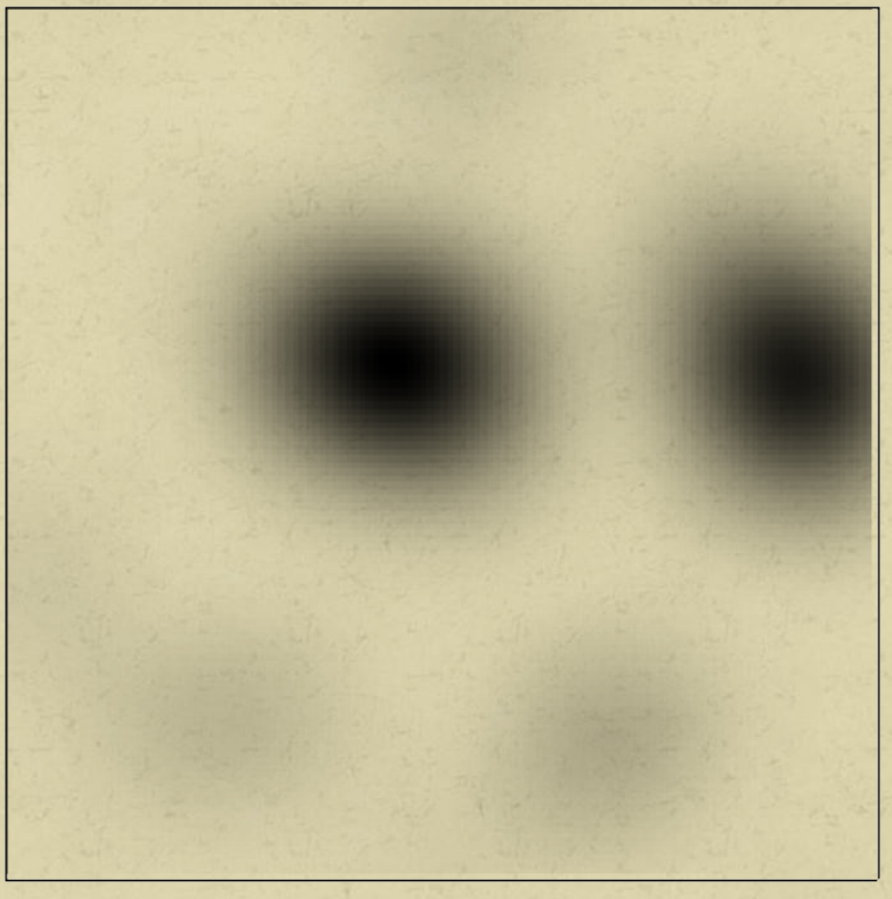
WAVELET APPROACH

Scale 5



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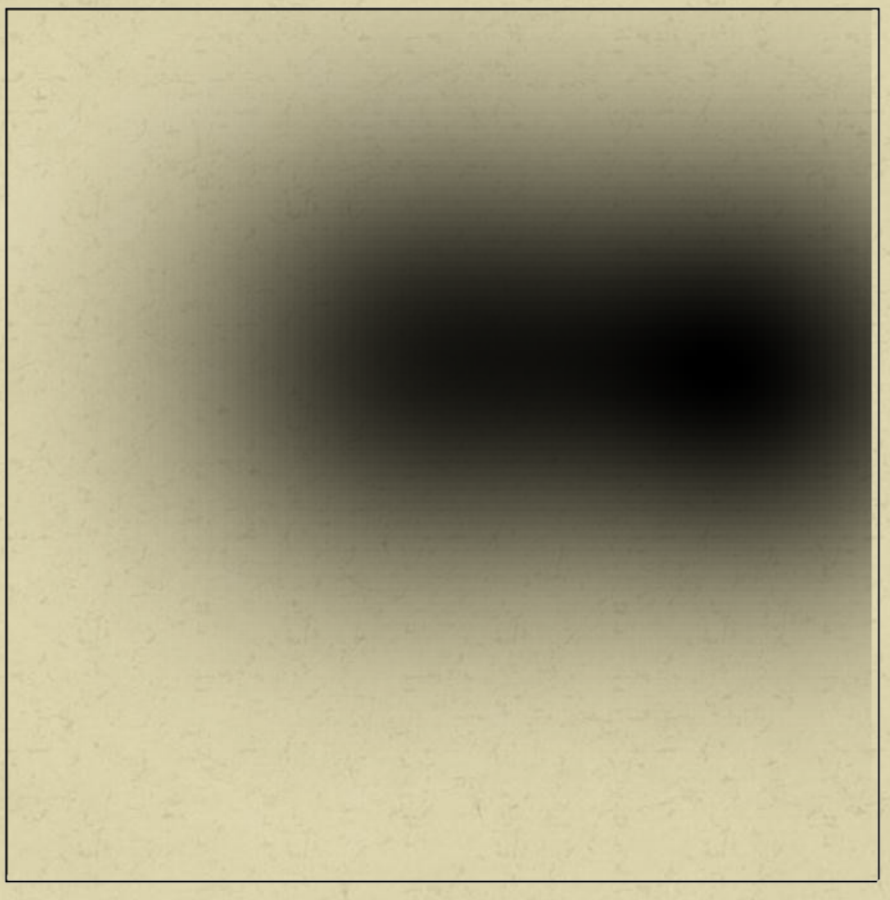
WAVELET APPROACH

Scale 6



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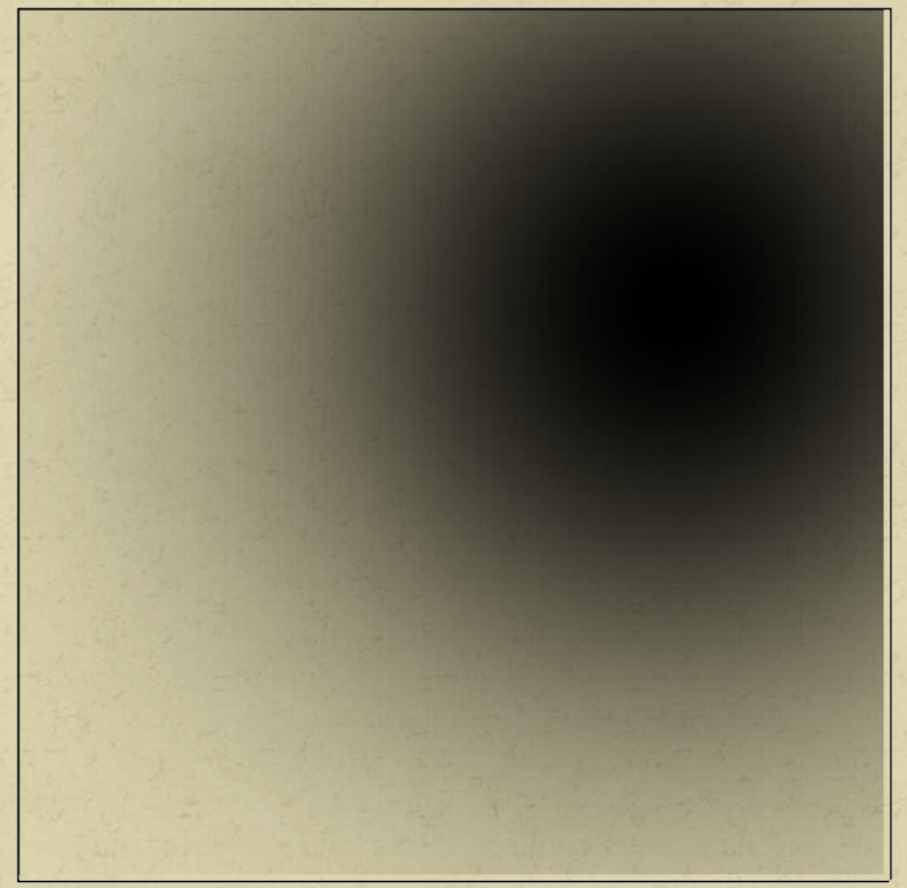
WAVELET APPROACH

Scale 7



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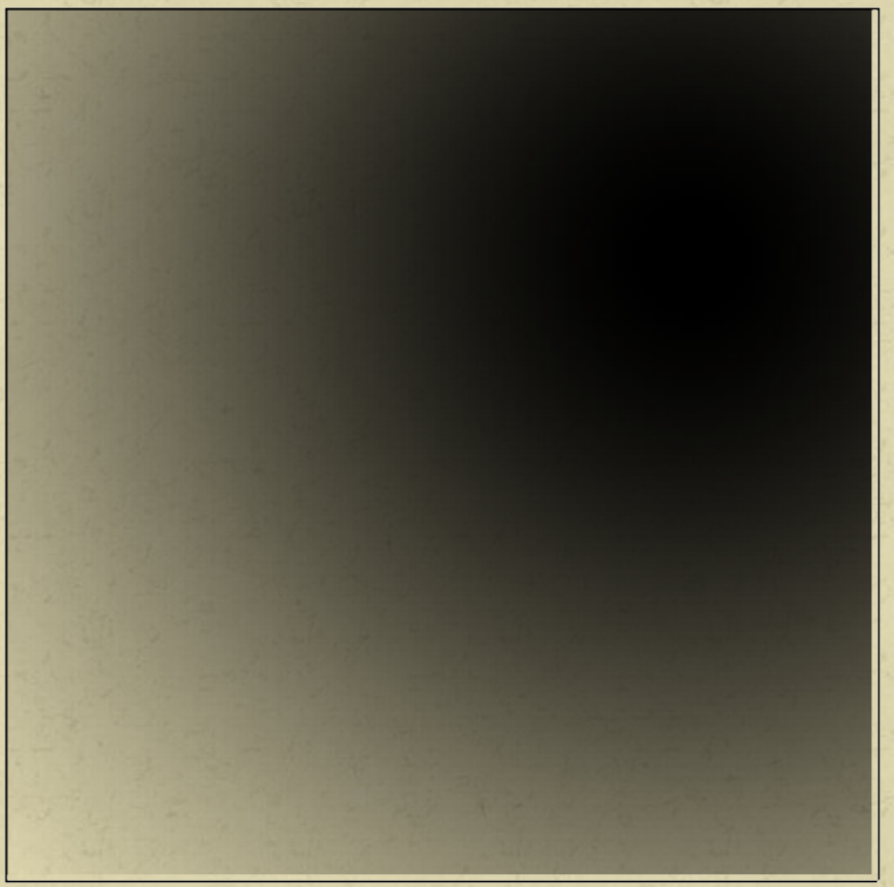
WAVELET APPROACH

Scale 8



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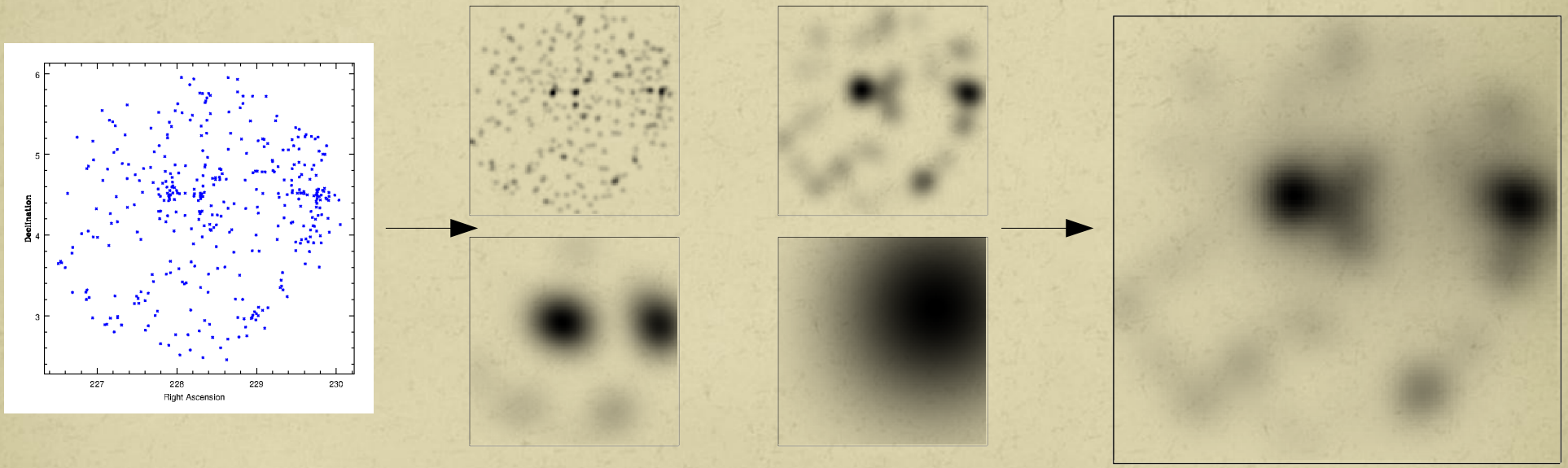
WAVELET APPROACH

Evaluation of distribution functions

Projected density maps :

- Point catalog
- Perform the wavelet decomposition (pixel size)
- Build the final map considering only some scales



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MORPHOLOGY

1. Along the line of sight
   - Select galaxies within 1Mpc around cluster centers

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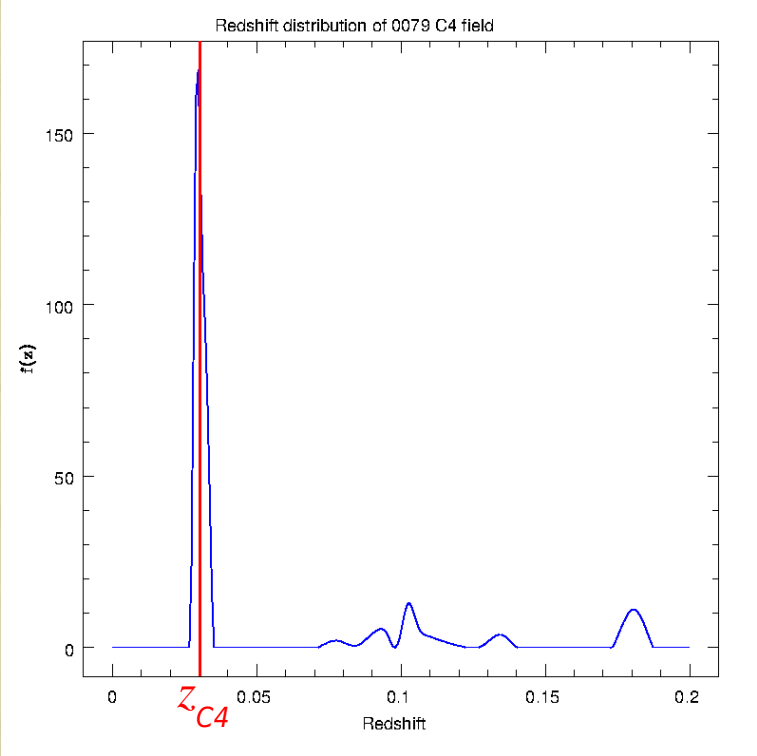
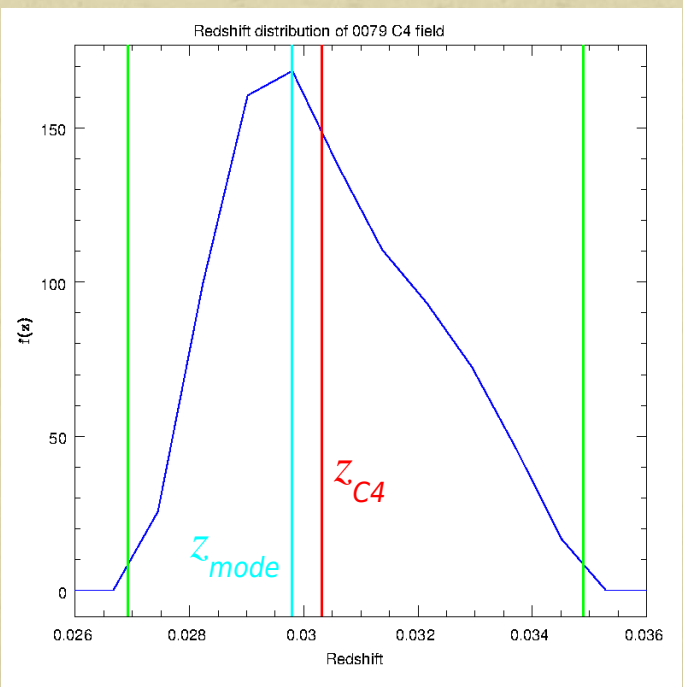
   - Compute Redshift Distribution Function (RDF)



MORPHOLOGY

1. Along the line of sight
   - Select galaxies within 1Mpc around cluster centers
   - Compute Redshift Distribution Function (RDF)
   - Cluster redshift → mode
   - Cluster redshift interval

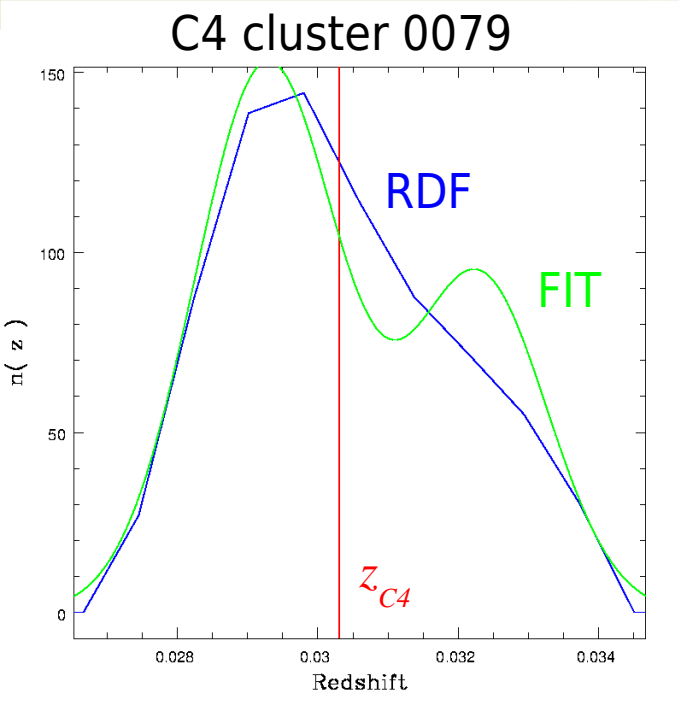


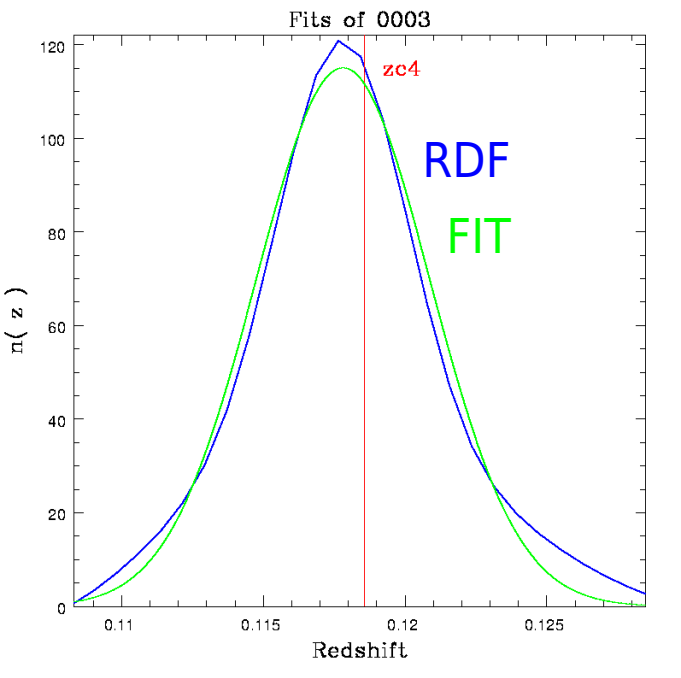
MORPHOLOGY

1. Along the line of sight

- Decomposition of galaxy **redshifts** into Gaussian mixtures using EMMIX software : EMMIX fits galaxy redshifts by one or several Gaussian laws

EMMIX software : McLachlan & Peel 1999



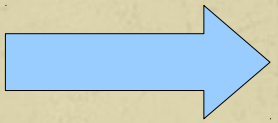


MORPHOLOGY

1. Along the line of sight

- Decomposition of galaxy **redshifts** into Gaussian mixtures using EMMIX software : EMMIX fits galaxy redshifts by one or several Gaussian laws
- Remove Gaussian peaks with velocity dispersion lesser than 150km/s
- Gaussian hypothesis assessed by χ^2, skewness S, kurtosis K and normality tests

EMMIX software : McLachlan & Peel 1999

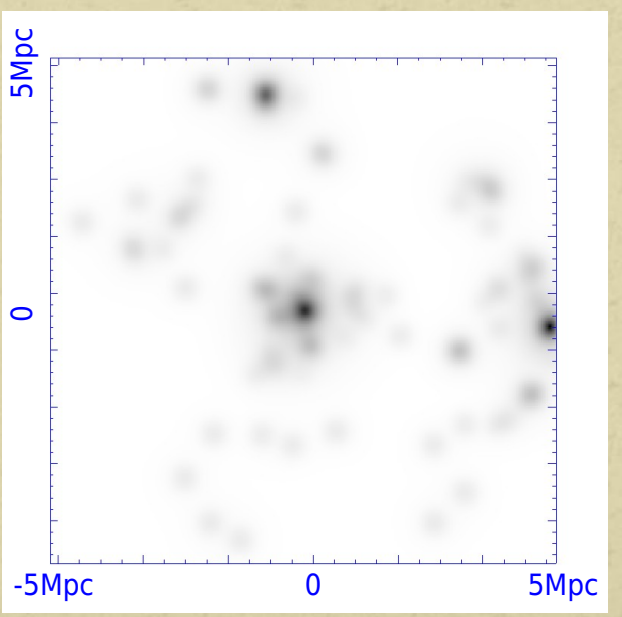


$$N_{peaks}\ (\bar{z}_{peak},\ \sigma_{peak},\ N_{gal,peak}),\ (\chi^2,\ S,\ K\ ....)$$

MORPHOLOGY

2. In projection on the sky plane

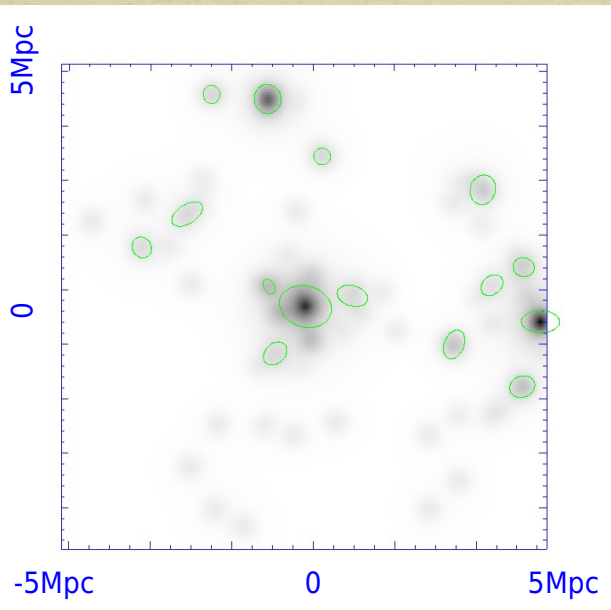
- Select galaxies with redshift in the cluster redshift interval
- Compute density map considering scales from 0.5Mpc to 2Mpc



MORPHOLOGY

2. In projection on the sky plane

- Select galaxies with redshift in the cluster redshift interval
- Compute density map considering scales from 0.5Mpc to 2Mpc
- Detect and characterize clumps with SExtractor



Clump properties

N_{clumps}, (α, δ), a, b, (ε), θ, F

MORPHOLOGY

Summary : catalog of clusters

- Determine cluster redshift interval
- Gaussian decomposition : N_{peaks}, ($\bar{z}_{peak}$, σ_{peak}, $N_{gal,peak}$)
- Quality of Gaussian fit : χ^2, S, K ....
- Clump decomposition : N_{clumps}, (α, δ)
- Shape parameters : a, b, ε, θ
- Richness : F

Compute 3D distances between structures & richness ratio

CLUSTER CLASSIFICATION

1.Regular clusters: 21%

1 Gaussian peak & 1 clump
(no 1:10 neighbour within 2Mpc)

2.Major multimodal clusters: 28%

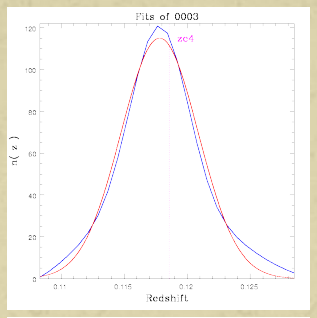
at least 2 main components
(1:1-1:5 within 2Mpc)

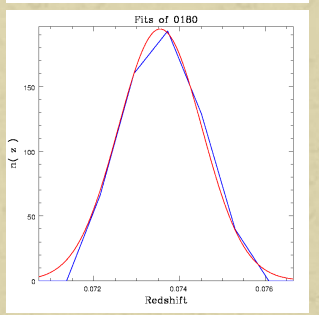
3.Minor multimodal clusters: 40%

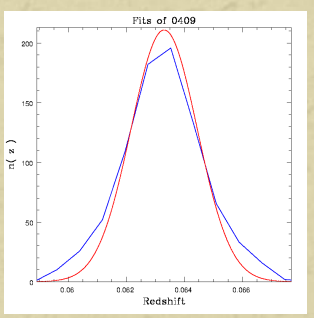
one main clump with several less massive components (1:5-1:10 within 2Mpc)

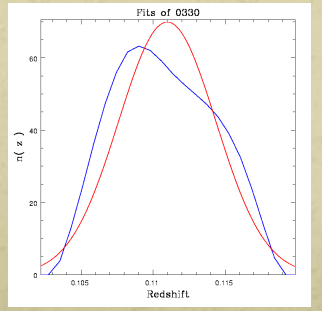
4.Irregular unimodal clusters: 11%

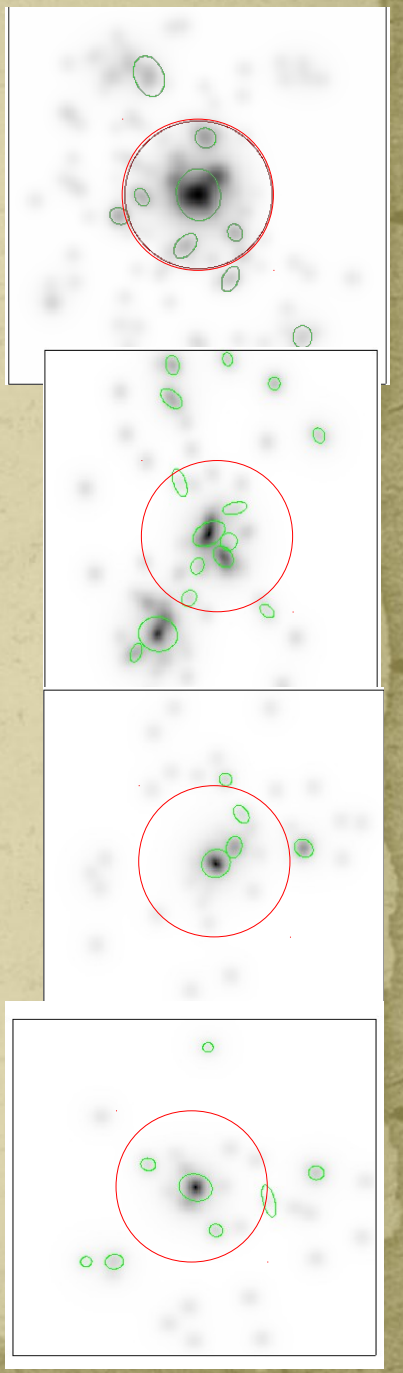
1 non Gaussian peak and/or 1 non spherical clump (no 1:10 neighbour within 2Mpc)











PERSPECTIVES

- Compare with X-rays : subsample of ~25 clusters

  (XMM & Chandra)

  ↳ Evaluation of cluster dynamical state

- Study the correlation between cluster morphology and :
  - the position of the BCG
  - galaxy colors/SFR

- Study the impact of using z_{phot} instead of z_{spec}

  → extension to larger and/or deeper surveys (CFHT-LS, DES, EUCLID ....)

- Study scaling relations

CONCLUSION

New cluster morpholgical classification

21 % of unimodal regulars
28 % of major multimodals
40 % of minor multimodals
11 % of unimodal irregulars

Deeper surveys (CFHT-LS, DES, EUCLID ....) :

Evolution of cluster morphology
Cosmology

THANK YOU